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TIDAL FRICTION.

Scientific Papers. By Sir George Howard Darwin, K.C.B., F.R.S. Vol. ii., Tidal Friction and Cosmogony. Pp. xvi+516. (Cambridge: University Press, 1908.) Price 15s. net.

THE papers in this volume form a collection which is especially interesting for several reasons. They are in effect parts of a single investigation, they were all written within a period of about three years (1879-82), and they form the foundation for more than one of the views in regard to cosmogony which are now widely accepted among scientific men. The following papers are included in the volume:— (1) On the bodily tides of viscous and semi-elastic spheroids, and on the ocean tides upon a yielding nucleus, (2) Note on Thomson's theory of the tides of an elastic sphere, (3) On the precession of a viscous spheroid, and on the remote history of the earth, (4) Problems connected with the tides of a viscous spheroid, (5) The determination of the secular effects of tidal friction by a graphical method, (6) On the secular changes in the elements of the orbit of a satellite revolving about a tidally distorted planet, (7) On the analytical expressions which give the history of a fluid planet of small viscosity, attended by a single satellite, (8) On the tidal friction of a planet attended by several satellites, and on the evolution of the solar system, (9) On the stresses caused in the interior of the earth by the weight of continents and mountains. These researches may be described as classical. In the reprint the papers have for the most part been left very much in the form in which they were published originally. It would have been possible, as the author points out, to re-write them as a compact treatise. On account of their great importance as original sources of information, and as pioneering work in a subject that is at once extremely fascinating and beset by unusual difficulties, it is likely that this carefully edited reprint will be more valuable than such a treatise.

The underlying thesis which pervades the volume is that, whatever the actual constitution of the earth may be, it must be more or less plastic. Although it may behave as a solid, and even as a very rigid solid, in regard to many types of forces, yet it must yield to great and long-continued stress almost as if it were fluid. For example, the figure it assumes in consequence of the diurnal rotation must be very nearly a possible figure of equilibrium of a rotating mass of gravitating fluid. In most of the problems discussed in the book the substance of the earth is treated as homogeneous and incompressible, and as resisting external forces in the same way as a viscous fluid. It is pointed out that a degree of viscosity which would be very large in comparison with that of ordinary fluids, as they are known to us, would produce hardly any effect in a body of the size of the earth, and that a substance of such viscosity as is necessary to produce any marked effect on the tides would behave in regard to periodic forces almost like

a very rigid solid. Just as in many related questions, so here also, the enormous pressure exerted in the central parts of the earth by the weight of the super-incumbent material becomes, as it were, a natural standard of stress. If the tangential stresses within the earth are everywhere small in comparison with this pressure the viscosity must be considered to be small, even though it may be greater than any that we know by experiment. In several places in these papers approximate results are obtained by treating the viscosity as a small quantity in this sense.

An alternative hypothesis to that of pure viscosity is the hypothesis of "elastico-viscosity," which includes pure elasticity and pure viscosity as extreme limits. The results of this hypothesis, so far as they are worked out, are qualitatively so similar to those of the hypothesis of pure viscosity that it was not thought necessary to develop them in full detail. The errors due to the hypothesis of homogeneity are discussed in Paper 2. It was there shown, by the aid of a simplifying assumption, that the effect of heterogeneity would be to diminish the ratio of the disturbance of ocean level to the displacement of the surface beneath the ocean, and an estimate of the reduction was obtained. Later investigations have shown that the reduction of this ratio on account of heterogeneity is really greater than it was estimated to be, but this paper contains the first attempt to determine the change that is produced in the earth's potential by tide-generating forces.¹ The general result that the errors due to the hypothesis of homogeneity do not seriously vitiate the qualitative results of the theory, though they may affect the numerical details, is probably true also of the errors due to the hypothesis of absolute incompressibility.

The main contribution of these papers to cosmogony is in regard to the efficacy of tidal friction as a cause of change in the configuration of the system of earth and moon. The chief cumulative effect produced by the lagging of the tides is a transformation of the angular momentum of the earth's rotation into angular momentum of the relative orbital motion of the earth and the moon. It is shown to be possible to trace back the configuration of the system from its present specification to one in which the moon was very near to the earth, the day and the month were nearly equal in length, and much shorter than the day is now, while the inclination of the lunar orbit to the equator and the obliquity of the ecliptic were very much less than they are now. It is concluded that probably the moon was once part of the earth, and that it broke away in consequence of some kind of instability, in regard to which various possibilities are indicated. It is concluded further that probably the changes in the configuration of the earth-moon system are mainly due to tidal friction, but that this cause of change has been much less efficient in the case of other planets and their satellites, and in the case of the solar system as a whole, although traces of the effects which it is competent to produce are discernible almost everywhere. Another important conclusion is

¹ Reference to this paper was omitted by an oversight in the article "The Yielding of the Earth to Disturbing Forces" in NATURE, April 29.

that the slackening of the speed of the earth's rotation, due to tidal friction, more than counterbalances the quickening due to contraction of the earth as a cooling body. On the other hand, it is shown that the heat that has been generated in the earth by tidal friction, although very great in absolute amount, hardly affects at all the temperature gradient near the surface. All these conclusions are nearly independent of the special hypotheses adopted in order to render the mathematical problem definite and comparatively tractable, and this independence is brought out in a highly instructive graphic method of discussing the problem by the aid of the general principles of energy and momentum, a method which was developed by the author after discussing the theory with Lord Kelvin.

A subsidiary effect of the viscosity of the earth's substance is found in a tendency for any elevation on the surface to be displaced gradually westwards by an amount which is greatest at the Equator. This result suggests that equatorial lands may tend to be displaced westwards relatively to polar lands, and it is therefore a step towards a solution of the dynamical problem of the distribution of land and water. The existence of the continental elevations and oceanic depressions shows conclusively that the earth behaves in some respects as a solid body of considerable rigidity. The last paper in the volume is a discussion of the strength and solidity which the materials of the earth must possess in order that such continents as actually exist may be supported without interior compensation. This paper is the only one which has been much altered from its original form, and in this instance it is the mathematical theory that has been re-written, the general argument being but slightly affected. The author would seem, from a passage in his preface, to have come to hold the view that the continents are not actually supported in the manner assumed in the paper as a basis of discussion, but his investigation remains the most important contribution that has ever been made to the problem.

Workers in mathematical physics will be grateful to the author for his careful revision, and to the Syndics of the Cambridge University Press for their public spirit in re-printing and re-publishing the papers. The author's custom of summarising his methods and results in language comparatively free from technicalities should render his general arguments and main conclusions accessible to all persons interested in speculative astronomy. A. E. H. L.

PAPER-MAKING.

The Manufacture of Paper. By R. W. Sindall. Pp. x+275. (London: A. Constable and Co., 1908.) Price 6s. net.

THE author is well known as a specialist and a worker in this branch of technology, and, of course, in a treatise of nearly 300 pages, could not fail to deal, in an interesting way, with some critical problems of the industry. But this contribution to the subject, which is of deep, wide, and varied interest, hardly commends itself as a spontaneous effort in relation to its literature. From our brief but "brotherly"

examination of its contents we are led to surmise that it owes its origin to mixed motives, such as would operate in the case of a publisher's "specification" adopted by the author, not as a call or inspiration illuminating as well as defining his task, but rather as a condition of a contract to be fulfilled. This somewhat artificial basis is already indicated in the pointless preface, in which the author first records some very obvious convictions, as to the complementary relations of engineer and chemist in this industry. But these are not applied as material to any purpose or plan of the present work, which is otherwise introduced in a paragraph of faint praise as follows:—

"In the present elementary text-book it is only proposed to give an outline of the various stages of manufacture and to indicate some of the improvements made during recent years."

The result is, as regards *matter*, a series of sectional chapters dealing with aspects of the industry and its processes, with no continuity or cohesion of plan; and as regards *form* there is not merely an absence of style, but a disregard of accuracy of definition and precision of statement which, in an elementary text-book, as it claims to be, is a usual feature of distinction as of moral influence on the mind of the student reader. It is a depressing task for a reviewer thus to record a depreciative estimate of a work which of course represents merit, as well as effort, on the part of the author, and it is equally thankless to have to justify such conclusions in detail. We can only lighten the task by shortening it.

The absence of plan is seen in the treatment of fundamental processes and effects, such as bleaching, beating, and sizing; matters of such general import are introduced in successive chapters dealing with different classes of papers without expository preparation. "Electrolytic bleaching" is treated in a detailed *exposé* of cost of production of the hypochlorite analysed into its factors. This, on the other hand, presumes a basis of critical knowledge on the part of the reader out of all perspective. The paper machine is introduced by way of photo-illustrations and a paragraph or two of descriptive matter; the reader is then rushed to the laboratory to test papers for the presence of mechanical wood-pulp; he is then rushed back to the machine for the task of calculating its output (pp. 119-25). The structural features of paper-making fibres are introduced at various points in the text by way of photomicrographs and descriptive remarks; but if the author were asked as to the educational effect intended, we think he would reply by stating that that is "a question of which he would require notice."

As regards form and the defects of the text in point of style and accuracy, examples might be taken from almost every page. Note the opening sentence:—"The art of paper making is undoubtedly one of the most important industries of the present day." Of course, we know what the author *means*, and in English composition this is the popular touchstone of language. A more typical example is the following (p. 40):—